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The Sustainment Management Support Project

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ABSTRACT

The Sustainment Management Support Project (SMSP) will assist Maritime Systems Division (MSD) to reduce its Logistics Cost of Ownership (LCOO) of maritime assets. To achieve this, a suite of software tools is being developed and it is essential that the tools utilise the same data sources and uniformly report their results. The SMSP provides the required common framework for the software tools. The SMSP suite of tools includes data collection and data cleansing; Condition-Based Maintenance (CBM); system reliability and availability analysis; inventory management; prediction of system and Royal Australian Navy (RAN) platform performance and costs for a range of operational profiles; objective decision-making; and identifying potential and actual throughput problems in the MSD business domain.

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The Sustainment Management Support Project

Executive Summary

The Sustainment Management Support Project (SMSP) is an advanced analysis system being developed to predict future sustainment requirements. It will assist Royal Australian Navy (RAN) capability managers to make informed decisions and thereby allocate available resources cost-effectively in relation to platform readiness and sustainability. The outcomes will give these capability managers the ability to maximise platform capability and quantitatively analyse capability management options in relation to maintenance and sparing policies for a range of operational scenarios.

The SMSP tool suite provides the means to perform calculations, deductions and predictions in support of capability management, based on a disparate body of facts, relationships and rules. Figure A shows the process flow within the SMSP to achieve these calculations, deductions and predictions.

The SMSP includes data collection and data cleansing; Condition-Based Maintenance (CBM); system reliability and availability analysis; inventory management; prediction of system and RAN platform performance and costs for a range of operational profiles; objective decision-making; and identifying potential and actual throughput problems in the Maritime Systems Division (MSD) business domain.

Two primary features of the SMSP are the: Information Portal that will ensure quality data input; and the Reporting Portal that will provide consistency, timeliness and ease of reporting, including a reporting functionality that can be customised to the needs of all levels in the chain of command (see Figure A).

The SMSP can be aligned with many of the Fundamental Inputs to Capability (FIC) and in so doing, the SMSP encompasses much of MSD's activity requirements. The SMSP will also contribute to a number of Product and Process Support areas within the RAN and the Defence Materiel Organisation (DMO).

This report describes the functionality of the SMSP, including the accompanying figure, and its contribution towards DMO goals. The primary purpose of the SMSP is to assist MSD reduce its Logistics Cost of Ownership (LCOO) of maritime assets. To achieve this, the suite of software tools described within this report is required and it is essential that the tools utilise the same data sources and uniformly report their results. The SMSP provides the required common framework.

The potential financial savings that will be realised when the SMSP is implemented and operational is difficult to estimate. However, non-financial benefits include: improved governance and accountability; improved capability management, particularly in the reliability, maintenance and support of platforms and systems; and improvements in workforce efficiency.

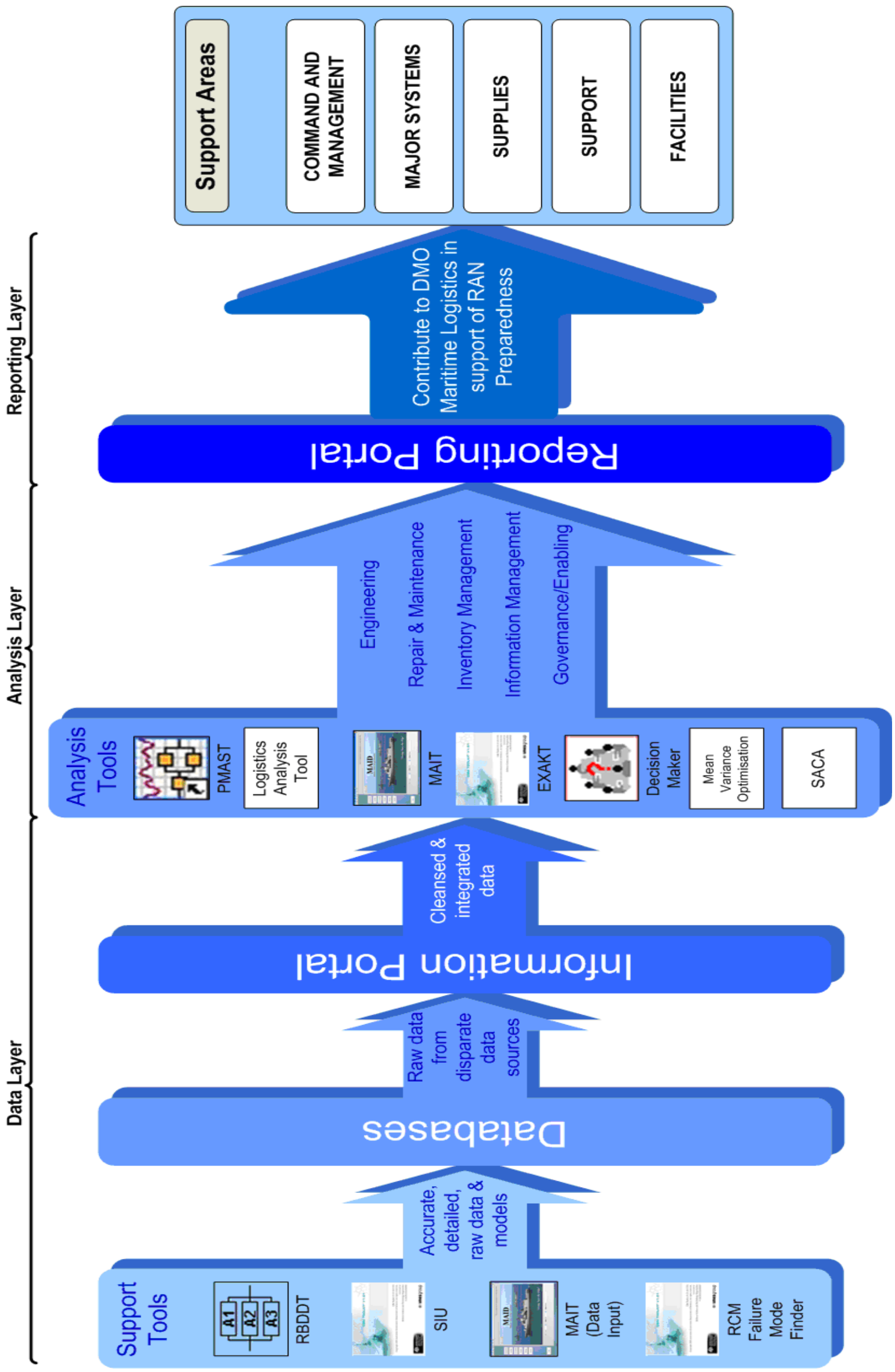

Figure A. The process flow within the Sustainment Management Support Project

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Anthony received a Bachelor of Science (BSc) Degree with Honours from the University of Tasmania in 1993. In 1995, Anthony joined Maritime Operations Division (MOD), Aeronautical and Maritime Research Laboratory (AMRL), where his research interests were in the field of Mine Hunting Detection Probability studies. In 1998, Anthony transferred to Maritime Platforms Division (MPD), AMRL, and conducted research in the area of data mining and Collins Class submarine systems analysis. Anthony's research areas with MPD have included Fremantle Class Patrol Boat Operational Relief studies; configuration management through the use of Reliability Block Diagrams (RBDs); and he was a Science Team Leader in Research and Development of ILS Tools for Sustainment Management Support. Still with MPD, Anthony's current research activities include SEA1000 Future Submarine Foresight planning; and submarine systems integration analysis.

Contents

Acronyms

AAS	Amphibious and Afloat Support
ACR	Allowance Change Requests
ADO	Australian Defence Organisation
AI	Artificial Intelligence
AMPS	Asset Management and Planning System
AMPS FMMS	AMPS Facilities Maintenance Management System
AMPS/PA	AMPS Procurement Automation
CAT	Capability Analysis Tool
C&M	Control and Monitoring
CBM	Condition-Based Maintenance
CEM	Capability Element Managers
CMT	Configuration Management Tool
CNSAC	Chief of Navy Senior Advisory Committee
CSARS	Class System Analysis and Reporting Software
DGMARSPT	Director General Maritime Support
DMO	Defence Materiel Organisation
DRN	Defence Restricted Network
DSTO	Defence Science and Technology Organisation
FAMT	Fleet Activity Management Tool
FFH	ANZAC Class Frigate
FIB	Force-In-Being
FIC	Fundamental Input to Capability
FMF	Failure Mode Finder
GUI	Graphical User Interface
IEC	International Electrotechnical Commission
IID	Independently and Identically Distributed
ILS	Integrated Logistics Support
IP	Intellectual Property
KPI	Key Performance Indicator
LAT	Logistics Analysis Tool
LCOO	Logistics Cost of Ownership
LIS	Logistics Information System
MAID	Maintenance Analysis and Input Demonstrator
MAIT	Maintenance Analysis and Input Tool
MCS	Monte Carlo Simulation
MPD	Maritime Platforms Division
MSD	Maritime Systems Division
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MSE	Materiel Support Evaluation
MVT	Mean Variance Tool
NAVALLOW	Navy Allowances
NIIN	North Atlantic Treaty Organisation Item Identification Number
NPS	Network Process Simulator

NSP	Navy Strategic Plan
OEM	Original Equipment Manufacturer
OA	Operational Availability
PHM	Proportional-Hazards Model
PMAST	Predictive Materiel Availability and Sustainability Tool
PMKeyS	Personnel Management Key Solution
RAN	Royal Australian Navy
RBD	Reliability Block Diagram
RBDDT	Reliability Block Diagram Development Tool
RCM	Reliability Centred Maintenance
RCOO	Reduced Cost of Ownership
SACA	Statistical Activity Cost Analysis
SAL	Ships Allowance List
SALIRS	Ships Automated Logistics Information Reporting System
SDSS	Standard Defence Supply System
SIU	Systems Interface Unit
SMSP	Sustainment Management Support Project
SOH	Stock On Hand
SPO	System Program Office
SRCO-MIS	Ship Repair Contracts Office Management Information System
UK	United Kingdom
USA	United States of America

1. Introduction

The Defence Materiel Organisation (DMO) has a single purpose [1]:

To equip and sustain the Australian Defence Force.

To achieve this purpose, DMO has defined a set of goals to achieve:

> *The DMO is committed to delivering capability and through-life sustainment of military equipment on time, on budget and to the required capability, safety and quality*.

This report describes the functionality of the Sustainment Management Support Project (SMSP), which contributes towards the DMO goals. The functionality developed and proposed by the SMSP will enable the DMO Systems Program Offices (SPOs) and the Royal Australian Navy (RAN) to make informed decisions and thereby allocate available resources cost-effectively in relation to platform readiness and sustainability. The outcomes will assist in maximising platform capability and availability; and the quantitative analysis of capability management options in relation to maintenance and sparing policies for a range of operational scenarios.

Sustainment contributes to RAN preparedness and, consequently, towards military capability, thereby enabling Australia to exercise military power [2]. Sustainment is defined as '*the provision of personnel, logistic and other support required to maintain and prolong operations or combat until successful accomplishment of the mission or the national objective*' [2]. Sustainment, therefore, is a functional component of Integrated Logistics Support (ILS) Management, Engineering Management and Inventory Management within the SPOs [3]. Essential to the development and delivery of military capability are the Fundamental Input to Capability (FIC) and it is the FIC shown below that define the elements of sustainment:

- COM – Command and Management;
- MAJ – Major Systems;
- SUP – Supplies;
- SPT – Support;
- FAC – Facilities;
- ORG – Organisation;
- COL – Collective Training; and
- PEO – People.

At the same time in the Navy Strategic Plan (NSP) [4], the short to medium term RAN intentions and requirements are identified. The NSP is a strategic level 12 month business plan, with a three year outlook after the date of issue, that addresses the priorities and performance management frameworks necessary to deliver capability. Through the NSP, resources are allocated, priorities assigned and detailed progress monitored. Within the NSP, the RAN Strategy Map, Figure 1, defines the performance management framework to measure the progress towards achieving RAN priorities and delivery of capability. That is, the contribution towards the Navy's Output. The Navy's Output is achieved by addressing the

RAN goals. The RAN goals, shown within the body of the RAN Strategy Map, are structured around five themes with each theme having a goal centred on the FIC. The RAN goals are:

- Leadership;
- Shape Our Future;
- Prepare for Operations;
- Build Partnerships; and
- People.

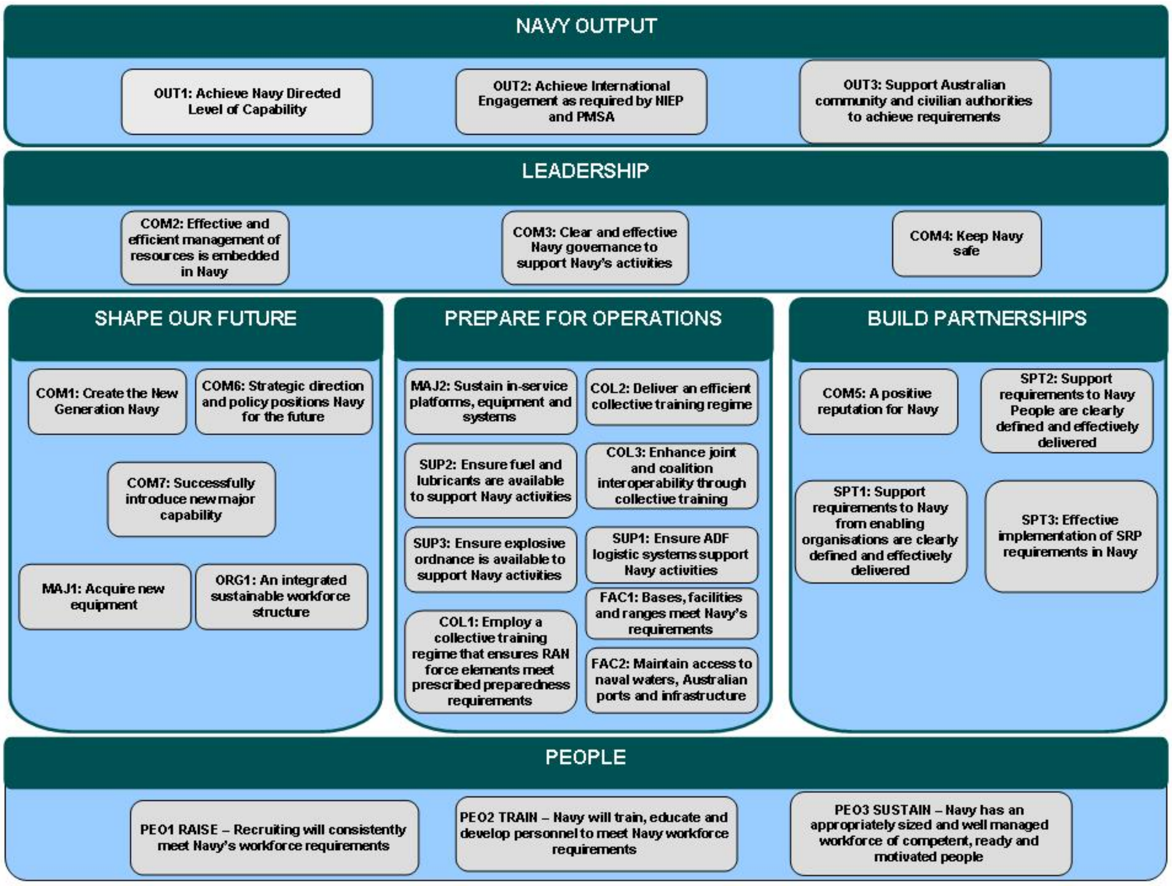

Figure 1: The RAN Strategy Map [4]

Organisations within, or aligned to, the RAN have their own Strategic Plans or Maps designed to contribute towards the RAN Strategy Map and NSP. These Strategic Plans and Maps were originally used to identify high level Project and Process Support areas within DMO and the RAN where the SMSP would contribute. However, due to the evolving nature of the Strategy Maps and the changing priority roles, it was decided not to link the SMSP directly with any Strategic Plans. Instead, the SMSP was aligned with the FIC, which are essential to the development and delivery of military capability. The FIC to which the SMSP contribute are shown in Figure 2. The arrow in Figure 2 indicates that the output from the SMSP contributes towards DMO maritime logistics in support of RAN preparedness. The Support Areas show five of the eight FIC to which the SMSP contributes. The three FIC not included are Organisation, Collective Training and People.

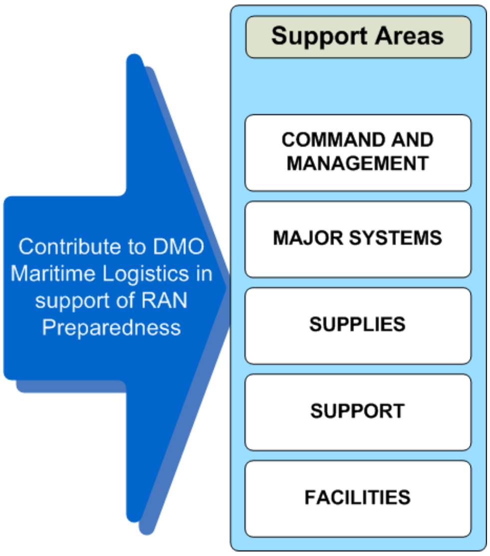

Figure 2: The FIC to which the SMSP contribute

The primary aim of the SMSP is to assist MSD reduce its Logistics Cost of Ownership (LCOO) of maritime platforms. To achieve this, a suite of software tools is required and it is essential that these tools utilise the same data sources and uniformly report their results. The SMSP involves the development of those software tools and aligns them in a common framework.

This report describes the functionality and process flow of the SMSP. The report only describes that functionality being developed for the SMSP. It is beyond the scope of this report to describe the numerous other ILS and Reduced Cost of Ownership (RCOO) related tools being developed within the Defence Science and Technology Organisation (DSTO).

In Section 2, an overview of the SMSP process flow is presented and the various tools introduced. Section 3 presents the *Data Layer*, which ensures accurate and quality data and models are input into various support databases. The Data Layer also facilitates the extraction of data from the databases. Section 4 describes the software tools in the *Analysis Layer*. These tools provide analysis in such areas as inventory management, maintenance management and business processes. Section 5 presents the *Reporting Layer* that facilitates prompt and consistent reporting. Section 6 discusses the SMSP in relation to the FIC and finally, in Section 7, concluding comments are presented.

2. The Sustainment Management Support Project

The SMSP supports the efforts and the conduct of the RAN Force-In-Being (FIB), thereby maintaining the fleet at a specified level of operational capability. Therefore, supporting the FIB is to support and sustain the fleet through a course of action at a prescribed operational state:

Sustainment *The provision of personnel, logistic and other support required to maintain and prolong operations or combat until successful accomplishment of the mission or the national objective.* [2]

The distinction between Sustainment and Sustainability, in a military context, is that Sustainability is the peacetime capacity to sustain a possible future military operation and Sustainment is to sustain an operation during wartime [5].

The means by which the SMSP supports the FIB is shown in Figure 3. This is the top level view of the process flow for the SMSP. Functionality has been developed and proposed for each of the areas: Data Layer; Analysis Layer; and the Reporting Layer. At the time of writing, some functionality still exists as conceptual ideas; some functionality is in prototype form; and some functionality is being trialled at the conceptual level within the SPOs.

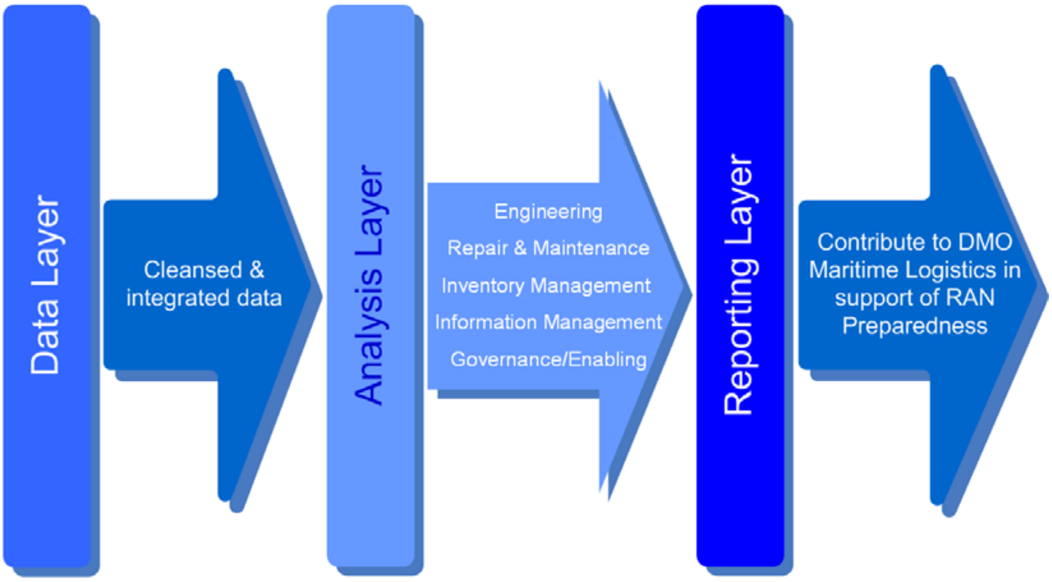

Figure 3: The top level functional view of the SMSP

The arrows within Figure 3 indicate the output each layer contributes to Sustainment Management Support. The functionality of each layer, and the contribution of the SMSP to RAN sustainment for preparedness, is described in later sections of this report.

Also, the arrows within the figure, and any subsequent related figures, do not represent the totality of information flow. The arrows indicate the ultimate contribution to the DMO and the RAN. Within each layer, there may be information feedback to previous layers.

The Reporting Layer provides for easy access to reports and results of analysis. It also facilitates access to the functionality within the Analysis Layer. Examples of functionality include: the Predictive Materiel Availability and Sustainability Tool (PMAST) for inventory management; and EXAKT for maintenance policy.

Logistics has been described as an art and a science benefiting from facts, relationships and rules used for calculation, deduction and prediction [6]. The Analysis Layer of the SMSP is

primarily where the logistics science is performed. That is, functionality within the Analysis Layer provides for the calculations, deductions and predictions. Calculations include failure probability and repair rate distributions; deductions include maintenance policy; and predictions include inventory management or system failures.

To perform the calculations, deductions and predictions, a body of facts, relationships and rules are required. These facts (for example: maintenance history data), relationships (for example: Reliability Block Diagrams (RBDs)) and rules (for example: SPO Business Rules) are usually stored within a database or, more generally, in many disparate databases.

The analysis tools send data requests to the Data Layer for specific data needs. The Data Layer 'knows' where that data exists and extracts it from the appropriate database(s). Functionality within the Data Layer ensures that quality and accurate data is input into several of the related logistics databases, especially those developed for the SMSP. The Data Layer also performs data cleansing and data aggregation.

The following subsections present an overview for each layer.

2.1 Data Layer

Data quality is critical for data analysis, so that realistic results, conclusions and recommendations are generated. The Data Layer ensures that quality, cleansed and integrated data is available to the analysis tools. Figure 4 shows the functionality and process involved in ensuring data quality.

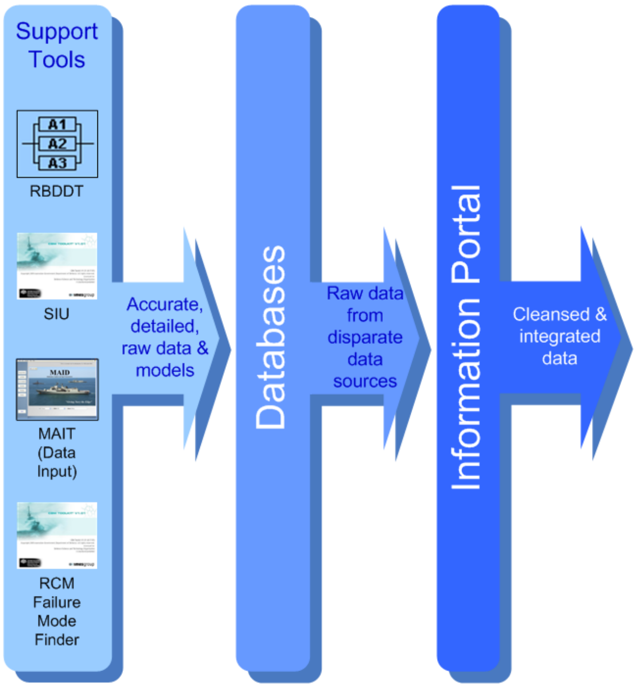

Figure 4: The functionality within the Data Layer of the SMSP

The Support Tools, described in Section 3, ensure that some ILS databases contain accurate and detailed information. Note that the Support Tools are designed for specific databases and will not affect data recording for every ILS database.

The Database Layer is a collective grouping of all associated logistics databases that contribute to the SMSP. These databases do not necessarily co-exist on the same computer server or even in the same physical location. They are disparate and owned by various organisations within the Australian Defence Organisation (ADO). The database layer is purely representational and it is not the intention of the SMSP to collect the databases into one location or common format.

The Information Portal is the layer that interacts directly with the databases; it is the bridge between the Analysis Layer and the databases. The Information Portal is designed to receive requests for data from the Analysis Layer and then extract the necessary data from the relevant databases. When the Information Portal receives the data it will then perform data cleansing operations, which may include manual data cleansing methods.

Utilising the Information Portal avoids direct interaction between the Analysis Layer and the databases. If changes were to occur to the databases, those changes need only be recognised by the Information Portal and will not require changes to all the analysis tools using those databases. The Information Portal maintains a consistent interface with the Analysis Layer and provides a measure of security since it is the only interface accessing the databases.

2.2 Analysis Layer

The Analysis Layer consists of a collection of Analysis Tools, as shown in Figure 5. The Analysis Tools contribute to a number of areas across ILS, Engineering, Repair and Maintenance, Inventory Management and Governance / Enabling. This is discussed further in Section 4.

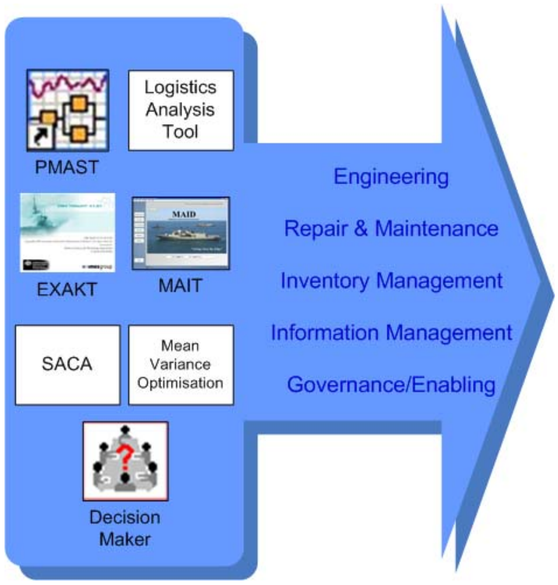

Figure 5: The Analysis Layer showing the icons for the SMSP analysis tools

2.3 Reporting Layer

The results from the Analysis Layer are passed to the Reporting Layer, which contains the Reporting Portal. In this layer, the information is presented in a form suitable for the end users.

The overall process flow for the SMSP is shown in Figure 6 (an expanded view of that shown in Figure 3). The intention of the Reporting Portal is to facilitate access to the tools, and results of data analysis by the DMO (and RAN) chain-of-command. In so doing, the SMSP contributes towards the support of RAN Preparedness via the FIC (shown in the column *Support Areas* on the extreme right of Figure 6).

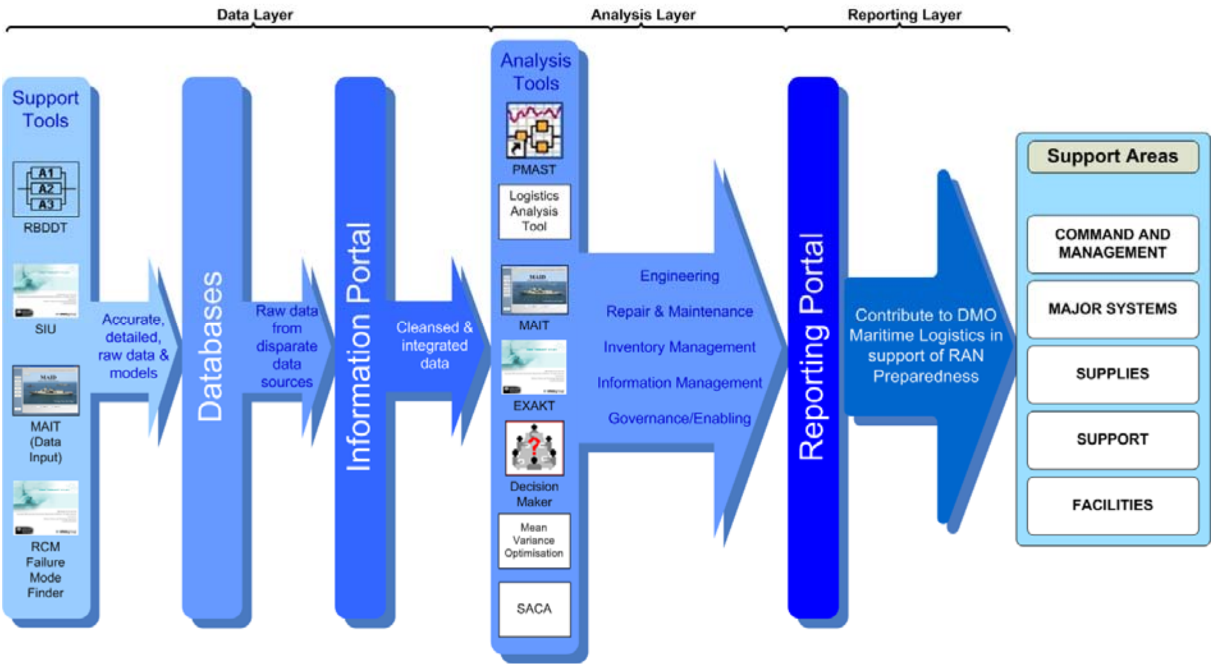

Figure 6: The overall process flow for the SMSP

3. Data Layer

As overviewed in Section 2, the Data Layer contains the Support Tools to ensure accurate, quality data and models are input into the respective databases. The support tools are described further in the following subsections.

3.1 Reliability Block Diagram Development Tool

An RBD schematically represents the serial and parallel relationships between systems, subsystems and components required to perform a given function. Furthermore, the functions

can be aggregated to form RBDs representing a given capability requirement. Simple, two component RBD structures are shown in Figure 7.

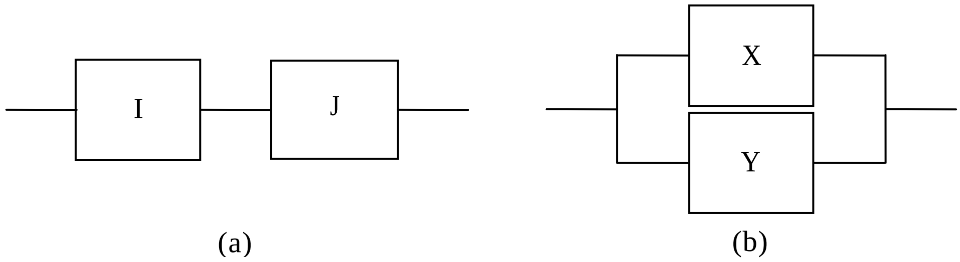

Figure 7: Two simple examples of RBDs. Figure (a) represents components in series; and Figure (b) represents components in parallel.

Figure 7a represents a system of two components in series. The system is operational only if both components I and J are operational. If either I or J fails, then the system fails. Figure 7b represents a system of two components in parallel. The system is operational if either X or Y is operational. If X fails, or if Y fails, the system continues to operate. If both X and Y fail then the system will fail.

After identifying systems and components that are required to perform a function, the next stage in the modelling process is to define the states of each system or component in the RBD and the mechanism of transfer between the states. For example, the states include: operational; failed and under repair; and failed and waiting for a spare system or component. The mechanisms of transfer include: 'operational' to 'failed and under repair'; 'failed and waiting for a spare' to 'failed and under repair'; and 'failed and under repair' to 'operational'. Each of these mechanisms of transfer may have an associated probability of success. The relationships represented by the RBDs assist in the analysis of determining whether a system will succeed or fail in its designed function or capability.

The Reliability Block Diagram Development Tool (RBDDT) is a proposed module that will allow RBD developers to easily input RBDs via a Graphical User Interface (GUI) and store the RBD as a directed graph [7]. The tool will also allow for entry of associated details such as failure modes, probability of failure and repair times for each system and component.

The RBDDT will not perform data analysis and will not generate results. The RBDDT database would be interrogated by the analysis tools and as such it would provide input to those analysis tools.

Data supplied by the RBDDT would include:

- system configuration;
- system failure modes;
- probability of failure; and
- Mean Time To Repair (MTTR).

The RBDs would contribute towards determining platform:

- serviceability;

- configuration status;
- operational viability of the components / systems; and
- materiel / maintenance support.

3.1.1 Current State

RBDs that have currently been developed for RAN platforms are stored in the Class System Analysis and Reporting Software (CSARS) database [8]. CSARS is the central repository, for each platform class, of all platform RBD definitions. It also facilitates direct links between each RBD component and the same component in the Standard Defence Supply System (SDSS), the Asset Management and Planning System (AMPS) and other decision support systems. As the central RBD repository, any RBD management support tool must access the RBD definitions in the CSARS database dynamically, without manually redrawing them in proprietary GUIs. The dynamic use of the RBDs in the CSARS database eliminates potential configuration management problems associated with RBD updates (such as avoiding multiple versions of the same RBD existing in several different commercial software packages). These RBDs could be configuration managed by the SPOs so there is only ever one RBD definition of any platform system. This also removes the Intellectual Property (IP) problem of several commercial packages having to access each other's RBDs. However, due to the complexity of RBD structures, storing them in a hierarchical format is not a viable solution. To overcome this they must be converted to a directed graph. The CSARS database is not capable of storing a directed graph.

3.1.2 Future

Development of the RBDDT would commence with the supporting RBD database structure definition. The RBDDT database would initially support PMAST and is required due to limitations in the RBD structure incorporated within CSARS. The components and systems of the RBD structures would also store associated platform positional information, failure modes and system functional performance degradation in the case of subsystem and component failures.

The RBDDT database would be designed to store RBDs as directed graphs. Tools such as the RBDDT and PMAST would then have the capability of interpreting the directed graphs.

Another aspect of the development of the RBDDT includes consolidating RBD constructs from military standards of the United States of America (USA) and the United Kingdom (UK) [9, 10] and other sources such as the International Electrotechnical Commission (IEC) International Standard [11].

Continued development of the RBDDT would provide to the user a GUI to facilitate construction of RBDs using 'drag-and-drop' techniques. This would allow the user to easily visualise the RBD on the computer screen. The underlining directed graph algorithm would ensure all RBDs are automatically converted and would maintain a standard for the RBDs across all platform classes.

Currently, the directed graph algorithm has been developed but the RBDDT database definition has only been informally specified. At the time of writing, further development of the RBDDT has ceased.

3.2 Systems Interface Unit

A necessary requirement for Condition-Based Maintenance (CBM) modelling is the need to access real-time, online, system condition data. The current control and monitoring system on the ANZAC Class frigates (FFH) is capable of logging data from a small number of sensors, which is then stored locally on removable, magnetic storage devices. However, this data is incomplete and inaccessible to personnel performing advanced analysis.

A control and monitoring enhancement project has developed hardware and software, known as the Systems Interface Unit (SIU), to extract all sensor and alarm data from the FFH control and monitoring system. The data collected by the SIU is transferred to a shore-based database for diagnostic and prognostic analyses. The interface between the SIU and the shore-based maintenance systems is via satellite and utilises a web browser interface, known as the CBM Toolkit. An image of the SIU, as installed on HMAS Ballarat, is shown in Figure 8.

Figure 8: SIU installation on HMAS Ballarat

The SIU will be used to provide condition-monitoring (sensor and alarm) data from the FFH control and monitoring system (consisting of approximately 3500 sensors) to an onshore control and monitoring database in a format accessible by the Data Abstractor (proposed as a

constituent part of the functionality of the Information Portal) and / or the CBM Toolkit for post-processing.

Analysis of SIU data can be used to provide information on:

- estimates for the economic consequences of failure;
- estimates for the cost of repair;
- condition-monitoring data for assessments of the general condition of systems;
- alarm monitoring data for assessments of the failed condition of systems;
- estimates for the time at which a component or system will need to be replaced or repaired based on its current risk trend; and
- estimates for the likelihood of transitioning from a low-risk to high-risk state, thus helping maintenance managers quantify the risks of postponing maintenance.

Development, testing and evaluation of the SIU is dependent on support from a number of organisations, including the ANZAC SPO, FFH crews (where trials are being conducted) and control and monitoring system Original Equipment Manufacturer (OEM) contractors.

Regular transfer of maintenance management data is dependent on access to, and successful transfer, via the NAVSYSLAN network and INMARSAT satellite links to the shore-based Defence Restricted Network (DRN) database.

At the time of writing, an initial nine month trial of the SIU has occurred on HMAS Ballarat, with data being collected during that time. A second SIU is also being trailed, this time on HMAS Arunta; however the trial is ongoing due to third party warranty issues.

3.3 Maintenance Analysis and Input Tool - Data Input

The Maintenance Analysis and Input Tool[1] (MAIT) [12, 13] is a discrete 'product' that provides functionality for quality data input and data analysis. The data input functionality provides quality control by analysing the data for completeness and accuracy. The data analysis aspect of MAIT provides support for reliability, availability and maintainability. For this reason, within the confines of this report, the MAIT data input and MAIT data analysis have been separated into two distinct parts. Therefore MAIT data input is considered a Support Tool within the Data Layer, as shown in Figure 6.

The Input Tool aspect of MAIT has been developed to investigate AMPS data quality. Prior investigations had determined that AMPS data quality was found to be unsuitable for engineering and costing analysis. It was discovered that the user interface was the source for much of these issues. MAIT data input addresses shortfalls with the AMPS interface and introduces new features to promote the collection of high quality maintenance data.

MAIT data input utilises data validation rules and provides feedback to the user regarding possible inconsistencies. It ensures accurate data is recorded in the AMPS database. MAIT also provides a data quality reporting function that analyses data records against an expected level

[1] MAIT: formerly known as the Maintenance Analysis and Input Demonstrator (MAID).

of detail and reports the probability of the record's inaccuracy or if the record contains an insufficient level of detail.

3.4 Reliability - Centred Maintenance Failure Mode Finder

Accurate CBM modelling requires knowledge of the occurrence of failure modes and for a consistent approach to the assignment of failure modes. Unfortunately, AMPS contains data that is neither complete nor accurate. For failure data, some data is recorded elsewhere other than AMPS. This does allow for manual assignment of failure modes by collating and synthesising the data from the disparate sources, however the scant data provided in AMPS is all that is available to assist in assigning failure modes. In isolation, this would generally not be sufficient for confident diagnosis. If the set of possible failure modes was significantly reduced by considering the event in an appropriate context, an experienced engineer or technician may possibly make a reasonable guess of the likely failure mode. Reliability Centred Maintenance (RCM) analysis provides this context and fortunately, for many FFH systems, RCM studies have been conducted and the data stored in a database.

The purpose of the proposed RCM Failure Mode Finder (FMF) is to provide an efficient method of assigning failure modes based on the sparse data available in AMPS and will allow for subsequent CBM analysis. The RCM FMF searches through RCM databases and assists experienced practitioners to make quantitative decisions on probable failure modes. This will enable determination of:

- the accurate classification of failures;
- the total number of failures;
- 'what if?' assessments of modified maintenance policies on the Operational Availability (OA) of systems and platform functions;
- the costs of a modified maintenance policy;
- the risk of failure during upcoming missions and the dependency on maintenance to reduce that risk;
- manning/support requirements of a modified maintenance policy; and
- the spares required to reduce risk during an upcoming mission.

Data cleansing is required to improve the reliability of the RCM FMF search engine. The cleansing involves fixing spelling mistakes and referential inconsistencies in the RCM and AMPS data tables. In the latter case, only the static tables such as the facility codes and compartment descriptions have been repaired.

For real time performance, the cleansed data should be recorded in the underlying database. However, there is reluctance by the system owners to modify historical AMPS data. This results in a significant and unnecessary processing burden each time the data is reused.

Errors in AMPS job details are not rectified since these need to be taken into account when performing the search and new jobs are continuously being recorded. Consequently, it is only feasible to search copies of the various data sources, rather than the real time data, since the results of data cleansing can be retained.

3.5 Databases

The Databases section of the Data Layer is a representation only of the collective grouping of databases accessed by the SMSP. The databases that the Data Layer should access include:

- CSARS [8];
- Ships Automated Logistic Information Reporting System (SALIRS) [14];
- SDSS [15];
- AMPS [16];
- AMPS / Procurement Automation (AMPS/PA) [17];
- AMPS Facilities Maintenance Management System (AMPS FMMS) [17];
- Navy Allowances (NAVALLOW) [14];
- Capability Analysis Tool (CAT) [18];
- Ship Repair Contracts Office Management Information System (SRCO-MIS) [19];
- Fleet Activity Management Tool (FAMT) [20];
- Personnel Management Key Solution (PMKeyS) [21];
- Configuration Management Tool (CMT) [22];
- RBDDT;
- PMAST [23, 24, 25] ;
- Logistics Analysis Tool (LAT); and
- the FFH control and monitoring database.

3.6 Information Portal

The Information Portal potentially provides a single interface to all potential data sources, thereby alleviating the problem of individual analysis tools having direct links with the databases. The Information Portal consists of a Data Source Abstractor and a Data Validator, as described in the following subsections.

3.6.1 Data Source Abstractor

The Data Source Abstractor potentially provides a single interface to all data sources. Security, connectivity and database language issues are managed by the Data Source Abstractor. The Data Source Abstractor outputs collated data related to specific equipment and systems as per the requirements of the requesting analysis tool.

3.6.2 Data Validator

The Data Validator outputs cleansed, verified and validated data. It receives collated data from the Data Source Abstractor and inspects each datum in context to determine whether the datum:

1. is valid;
2. can be corrected automatically; or
3. requires human intervention.

In the third case, the datum and details of any discrepancies are transmitted back to the originator for timely correction.

4. Analysis Layer

The Analysis Layer is where logistics calculations, deductions and predictions are performed. The Analysis Layer contributes to DMO, and RAN, processes in the areas of Engineering, Repair and Maintenance, Inventory Management, Information Management and Governance / Enabling, as shown in Figure 5.

In the area of Governance / Enabling, the Analysis Layer contributes primarily towards the MSD Operations Management and Finance sub domains in order to improve decision-making and hence improve MSD efficiency and effectiveness. Research is focused on developing conceptual models representative of various aspects of MSD business. The intention is for these models to be used in developing a range of practical tools and data constructs that coalesces contextual information from operations, management and finance to create synergies within the Governance / Enabling sub domains. The assumptions associated with this research are that:

- all relevant and accurate data is available; and
- input to output business relationships can be understood and modelled.

If the assumptions are maintained, the research will result in improved business decision-making.

The following subsections describe all the tools within the Analysis Layer.

4.1 Predictive Materiel Availability and Sustainability Tool

PMAST [23, 24, 25] is a modelling and simulation software tool used to predict the OA, spares and associated materiel costs of systems, subsystems and roles (such as, 'engage air targets') for a range of RAN platform operational profiles. It enables the SPOs, and the RAN, to make informed decisions and thereby allocate available resources more cost-effectively to maximise capability. It also allows for quantitative analysis of platform capability management options in relation to different maintenance and sparing policies. PMAST has the ability to model such things as: multiple systems and platforms; corrective and preventive maintenance; platform, base and depot level sparing; and rotatable pool / repairable items including recycle times and failure, repair and uncertainty distributions for each component.

PMAST has been designed to answer 'what if' questions in relation to OA, spares and costs such as:

- *What if roles change?*
- *What if financial resources are constrained?*
- *What if there are not enough on board spares?*
- *What if the sustainment period changes?*
- *What if corrective maintenance is not performed?*

The mathematical models of platforms; the logistics processes; and maintenance policies that have been implemented within PMAST are an approximation of the real world. To limit

potential misunderstandings of both PMAST inputs and outputs, it is important that all the implementation characteristics and assumptions that have been used in the modelling are documented. The modelling limitations and assumptions can be found in the PMAST Modelling and Simulation Characteristics report [24].

For the SPOs, the potential outcomes from the use of PMAST include improvements in spares allocations and, therefore, a reduction in LCOO.

4.2 Logistics Analysis Tool

The LAT is designed to perform two functions. Firstly, it determines the failure and repair probability distributions, and corresponding 95% confidence limits, of platform components. The second function is to extract, from multiple sources, data that includes: the Ships Allowance List (SAL); the Stock On Hand (SOH); times to supply; and component costs. This data and the subsequent LAT output is then made available for use with other readiness and sustainability tools, such as PMAST.

The LAT has an associated database used to minimise the time connected to multiple databases over the DRN and, consequently, reduce the potentially large usage of computer bandwidth. The database also facilitates the extraction of data from SDSS so that SDSS users do not experience degraded response times. Also, the LAT only requires infrequent use, for example once a week or once a month. This is because, temporally, most of the data will only undergo marginal changes. As a result, PMAST processing time will speed up since the LAT need not be used every time PMAST is used.

The primary assumptions associated with the development of the LAT are that:

- the underlying data is correct;
- all failures for the fitted equipment have been recorded in the AMPS database;
- the North Atlantic Treaty Organisation Item Identification Number (NIIN) issues data is correct for each facility code;
- the primary configuration is based on the CSARS system;
- all facility codes required for PMAST have a Materiel Support Evaluation (MSE) code;
- the required data is recorded in ADO Logistics Information Systems (LIS);
- all relevant information stored in ADO LIS is correct; and
- the data is Independently and Identically Distributed (IID).

The benefits of the LAT include calculations such as:

- repair distributions;
- associated uncertainty in the repair distributions;
- failure distributions;
- associated uncertainty in the failure distribution; and
- logistics delay time, such as base-to-depot, base-to-platform or depot-to-platform.

4.3 MAIT Data Analyser

MAIT was developed by the DSTO in response to an investigation of data quality within AMPS. The investigation found that AMPS data quality was insufficient for both engineering and costing analysis. MAIT addresses these issues and introduces new features to promote the collection of high quality maintenance data. MAIT is designed to be used with the current AMPS database without modification and provides a simple web-browser interface for the input of maintenance data and its analysis.

MAIT data analysis is performed in support of reliability, availability and maintainability analysis. It calculates the Mean Time Between Failures (MTBF); cumulative frequency distributions; and utilises Weibull and / or Exponential distributions, where appropriate, for the analysis. Feedback is also provided to the user informing them of the quality of the analysis and indicates the degree to which the data is relevant, accurate, complete and reliable.

MAIT's analysis capability provides the maintenance engineer with availability and reliability information data quality reports. MAIT can also can provide the current status of a platform's systems, based on maintenance that requires completion that affects system availability. The impact of future scheduled maintenance is also taken into consideration for determining system availability.

The output from MAIT includes:

- costs;
- required resources;
- MTBF;
- MTTR; and
- platform availability.

4.4 EXAKT

EXAKT is a CBM software tool, developed at the University of Toronto's CBM laboratory, for predicting the remaining useful life of a platform [26]. EXAKT models the ages of previous potential and actual failures and includes the condition-monitoring data leading up to those events. It takes into consideration the failure's economic consequences and generates an optimal policy for predicting potential failures. A Proportional-Hazards Model (PHM) [27] is used by EXAKT to join elements of condition data and failure data into a single risk function. The PHM hazard function can only be determined for failure modes with associated historical data, however, due to the numerical and theoretical models utilised by EXAKT, only a small number of failures are required.

EXAKT is a form of decision analysis that will provide added functionality to AMPS by allowing the maintenance manager to perform 'what if' type calculations. For example, a question may be, '*what will be the downtime/availability/reliability cost of my system if I double/triple/halve the overall frequency of some maintenance activity?*' EXAKT will generate a recommendation supporting a stated management objective. These objectives typically:

- minimise cost;
- maximise the platform's availability; and
- achieve a particular Key Performance Indicator (KPI), for example ratio of planned to breakdown maintenance.

EXAKT provides an estimate of:

- the economic consequences of failure;
- the cost of repair;
- costs of a modified maintenance policy;
- the time to repair or replacement for a platform based on its current risk trend;
- the likelihood of transitioning from a low-risk to high-risk state, thus helping maintenance managers quantify the risks of postponing maintenance;
- identify the condition-monitoring measurements that are useful indicators of failure in the relevant operating environment;
- risk of failure during an upcoming mission and the dependency on maintenance to reduce that risk;
- manning / support requirements of a modified maintenance policy; and
- spares required to reduce risk during an upcoming mission.

EXAKT has a number of assumptions, including:

- the change in system state from 'healthy' to 'failed' can be modelled as a non-homogenous Markov[2] process;
- the remaining life of a component or system (or its likelihood of failure) is dependent on the underlying hazard function[3] and associated event parameters[4];
- preventive maintenance can assume that risk is independent of age;
- decisions are only made at discrete time points;
- the cost of failure exceeds the cost of preventive replacement;
- optimisation is based on decreasing the total cost per unit time (in dollars or equivalent availability); and
- event data can be accurately assigned to specific failure modes.

EXAKT also has a number of limitations, including:

- engineering expertise is required to assign failure modes to failure / maintenance events and to define diagnostic indicators that are most appropriate for a particular failure mode or groups of failure modes;
- the PHM hazard function can only be determined for failure modes that have associated historical data. That is, a failure mode must have occurred in the past and accurate data must be available for modelling; and
- currently, there is a lack of condition data and events data.

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2 A Markov process is a discrete-time, stochastic process with the Markov property (that is, future states are independent of the past states). The present state description fully captures all information that can influence the future evolution of the process.

3 The hazard function describes how the hazard (that is, risk) changes temporally.

4 Event parameters describe events that can affect system condition, such as the operating conditions, running hours and choice of maintenance activity.

4.5 Decision Maker

Decision Maker is an objective decision-making tool that can be used in most multi-criteria decision-making problems, in particular, where a holistic approach is required in preference to the subjective and ad-hoc processes that are often applied [28, 29].

Decision Maker helps ADO planners deal with the complexities of military planning by providing a sound scientific basis to assist in decision analysis in a timely manner, as well as providing the decision-maker with a documented quantifiable justification for their decision basis. Examples where Decision Maker can be applied include:

- selecting the most preferred product, tender, service or company that best satisfies the specified requirements, criteria or objectives (that is, in procurement); and
- ranking the performance of systems, components or items using combinations of several performance measurements.

Unlike most other decision-making products, Decision Maker does not use subjective criteria to aid in the decision-making process. Research has indicated there is no other software on the market that incorporates all of the features of Decision Maker, in particular, the use of the objective weighted criteria method and genetic algorithms for sensitivity analysis. Other features include:

- the use of sophisticated mathematical analysis techniques to identify conflicts in data input by the user;
- non-independent criteria / objectives;
- a simple cardinal ranking of alternatives;
- removing the dependency on personal preferences of the decision-maker, resulting in informed and quantifiable decision choices;
- a unique sensitivity analysis component utilising leading edge Artificial Intelligence (AI) techniques to provide analysis for ‘what if’ situations;
- a simulation engine to allow decisions to be modelled with uncertainties and tolerance levels for criteria;
- advanced graphical analysis tools that provide the decision-maker with a means of comparing alternative criteria and objectives in a meaningful and timely manner;
- advanced simulation reporting analysis in tabular and graphical format, providing a means to quickly identify the superior alternative criteria; and
- graphical analysis tools that provide a means of determining complex relationships and trends within the criteria / objective data.

Decision Maker, the tool, assumes that the decision-maker, the person, can structure the decision problem according to the required priorities. It is not designed to make decisions but rather, provides a quantitative analysis comparison of various competing alternatives to assist personnel in short listing available alternatives. Decision Maker does not provide for qualitative input.

Decision Maker allows for refined decisions by providing a methodological and structured decision-making environment, which results in improved planning decisions.

4.6 Statistical Activity Cost Analysis Network Process Simulator

The Statistical Activity Cost Analysis (SACA) Network Process Simulator (NPS) is a prototype software tool that allows the user to set up and simulate complex process management networks to identify potential, or actual, throughput problems. For example, modelling the arrival and processing of work orders / work package development in an engineering support organisation.

A graphical point-and-click interface is used to set up complex interconnecting process networks that describe a workflow of interest with various types of nodes and links. The tool then performs Monte Carlo Simulation (MCS) to generate realistic cost and timing distributions for typical tasks. In this way, the user can identify:

- mean time and cost for typical jobs;
- variability of time and cost for typical jobs; and
- waiting times and queue lengths at individual nodes within the process.

Such process models can identify bottlenecks and areas that experience less use in the process networks studied. In particular, non-linearities in the network / system, where a modest increase or reallocation of resources can result in significantly higher throughput, are easily identified. Unlike more conventional simulation tools, the NPS allows the user to include variability in costs and durations at all points in the simulation. This allows, for instance, the effects of a more relaxed policy on turnaround time to be measured. The tool was designed to simulate process management within the Amphibious and Afloat Support (AAS) SPO, but has much broader applicability to other areas in the ADO.

4.7 Mean-Variance Tool

The Markowitz [30] mean-variance model is commonly used in the financial investment industry to select portfolios of investment options that provide minimum risk at given levels of return. This technique has been adapted to select minimal risk work packages for RAN platforms.

A simple to use prototype software tool has been developed, using standard mean-variance concepts, for the optimal selection of RAN platform maintenance and update / upgrade of work packages. It is not necessary to understand the mathematics underpinning the mean-variance model to use the software tool.

Operating the software will require only modest data entry and involves filling out three tables:

1. a table listing each ‘Work Package’ and its associated upper and lower costs;
2. a table listing the ‘Mission Types’ relevant to the platform and ranking the overall importance of each; and
3. a table ranking the increase in capability associated with each individual ‘Work Package’ against all relevant ‘Mission Types’.

A knowledgeable individual would be expected to be able to enter the data, from either personal knowledge or available data, in less than two hours.

A number of reports will be output from the software, including a graphical representation of the mean-variance efficient frontier[5] based on the simulation of a large number of random portfolios of work package combinations. Selection of a set of work packages that lie on the efficient frontier ensures the best possible increase in capability given an overall uncertainty level in costs.

Advantages of the mean-variance approach as an aid to configuration management decision-making include:

- modest data entry;
- a selection of work package options from the efficient frontier lowers the risk in funding a set of sub-optimal work package options;
- the ability to maximise overall platform capability for a given level of funds;
- the ability to minimise costs for a given level of overall platform capability; and
- the software and data entered can be shared, hence making the underlying assumptions visible to a group thereby leading to group agreement/consensus on ranking and cost variability data.

Furthermore the mean-variance approach has the potential to be extended to other sustainment decision-making areas. This includes:

- selecting the optimal mix of services to support DMO products; and
- selecting the optimal mix of funds allocation within and between DMO products.

5. Reporting Layer

The Information Portal and the Reporting Portal allow for a common interface between two main levels of the SMSP. The Information Portal provides an unseen (to the user) interface between the analysis tools and the databases. The Reporting Portal gives the users a common interface, which (eventually) they would be able to customise to suit their needs. To achieve the intent of the SMSP, the Reporting Portal needs to be accessible to all levels within the DMO, and RAN, hierarchies and be customised to suit the needs of each level. At the top level, the resources available to the Reporting Portal can be utilised to contribute towards Product and Process Support within the DMO, as shown in Figure 6.

5.1 Reporting Portal

The Reporting Portal is a web-based application designed to allow large quantities of heterogeneous information to be grouped, structured and delivered to the desktop via Microsoft Internet Explorer. The Reporting Portal is fundamentally a filing system for both traditional information (such as documents and images) and dynamic content produced by the analysis tools. The Reporting Portal stores four kinds of data:

- actual content, consisting of static documents and images;

5 The efficient frontier is where there is the lowest risk for a given level of return.

- references to content accessible by a Uniform Resource Locator (URL);
- metadata describing content; and
- a structure of linked 'information contexts' used to generate the Reporting Portal navigation construct.

The Reporting Portal is an Adobe Flash application written in Actionscript 2.0. This flash code accesses a knowledgebase via a web services layer written in ASP.NET. The knowledgebase can reside in any Object Linking and Embedding, Database (OLEDB) compliant database. The current implementation uses a Microsoft Access database.

The focal point of the Reporting Portal is the information contexts, examples of which are shown in Figure 9. An information context is analogous to a file system or email folder in that it groups related information. For example, "F150 Starboard Diesel Engine Sensor Data" could be considered a context that groups all information relating to instrumentation sensors mounted on the Starboard Diesel Engine of HMAS Anzac. The Reporting Portal allows contexts to be organised such that they can have multiple 'parents' and 'children'. Consequently, it differs from most document management systems that enforce a simple hierarchical approach (that is, one parent and multiple children). The advantage of the Reporting Portal's context is that the contexts can be navigated in a variety of ways and can more intuitively accommodate the needs of a wide variety of users.

Figure 10 shows the information context for HMAS Ballarat. In this context, the available information relates to the port and starboard diesel engines. These are the children information context for the HMAS Ballarat information context. The user may select one of these contexts to obtain information relating to the diesel engines. In this example the user has chosen to examine the starboard diesel engine (DE2) turbo charger speed, as shown in Figure 11.

It is envisioned that the Reporting Portal be customisable to suit the needs of various levels in the DMO and RAN chain-of-command. The ability to customise the reporting feature will allow for consistency across all levels of reporting. The Reporting Portal could assist Fleet Commander Australia by providing input into any reports required by the Chief of Navy Senior Advisory Committee (CNSAC) regarding Joint Capability Preparedness combined with input from the Capability Element Managers (CEMs) and Force Group Commanders. The Reporting Portal will aid in ensuring consistency between reports of Capability Preparedness and reports of Sustainability.

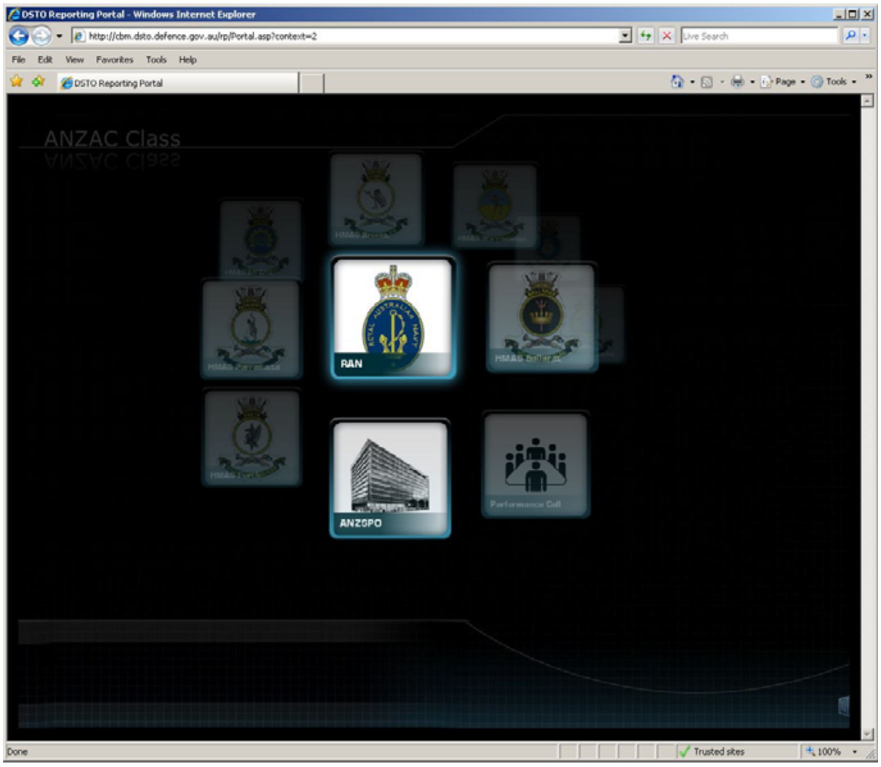

Figure 9: Reporting Portal screen capture showing the ability to service multiple platforms

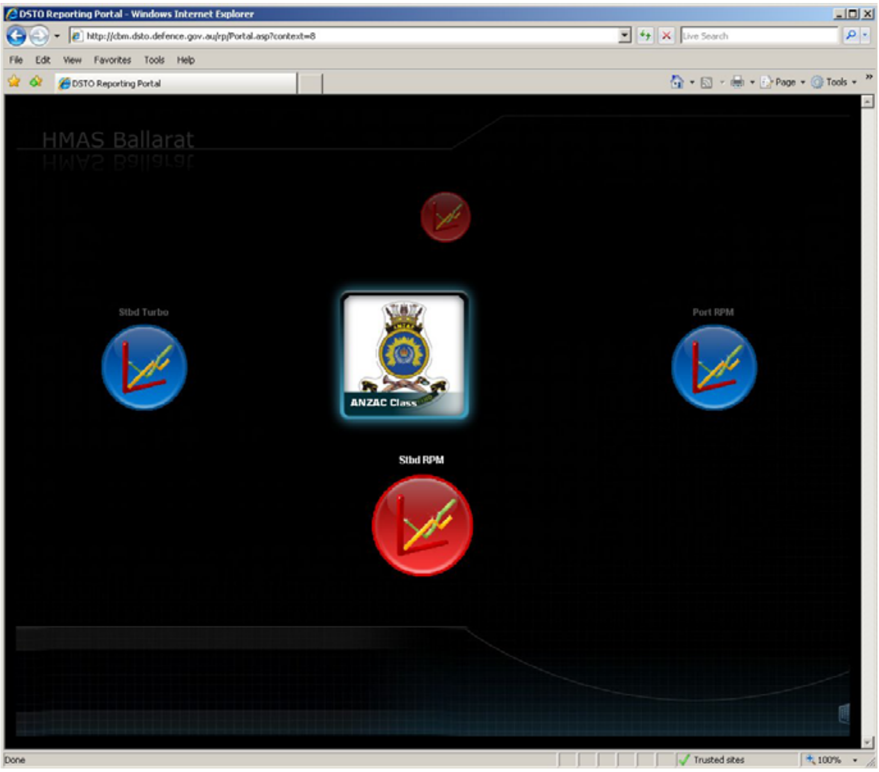

Figure 10: Reporting Portal screen capture showing information contexts available for HMAS Ballarat

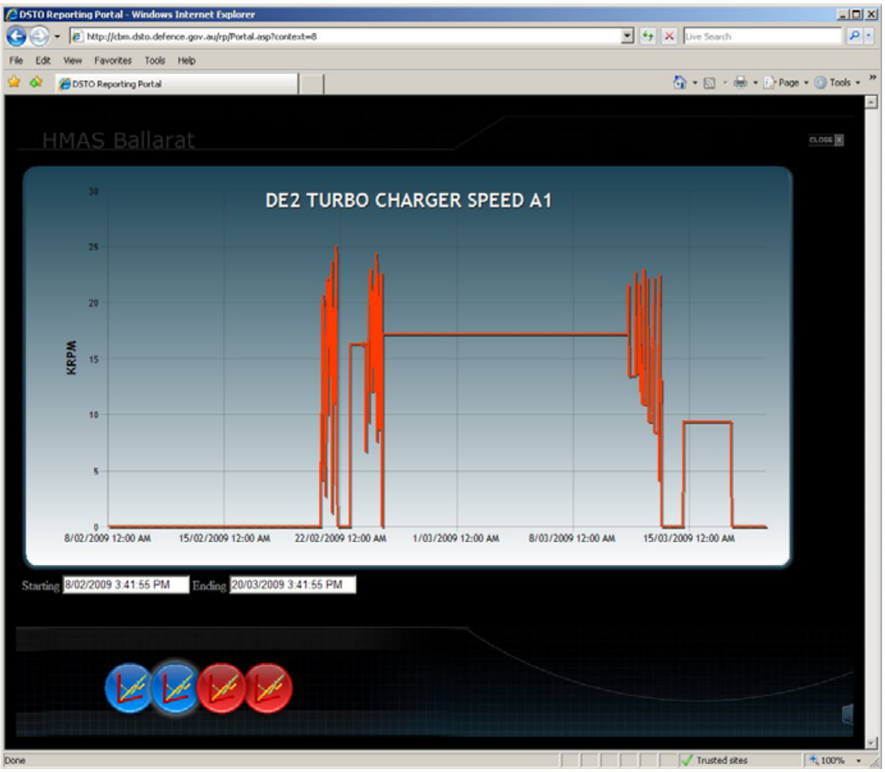

Figure 11: Reporting Portal screen capture showing graphical presentation for HMAS Ballarat diesel engine number two turbo charger speed

6. Linking Sustainment Management Support to the FIC and MSD Activities

Sections 3, 4 and 5 presented the suite of software that contributes to the SMSP. Figure 12 maps the relationship between the SMSP and the FIC and as can be seen in the figure, the SMSP contributes to nearly every FIC. The areas not supported are Organisation, Collective Training and People. However, these may be supported within other areas of the DSTO, which, as has been stated, are outside the scope of this report.

It must be noted that tools such as PMAST do have a People component, however the FIC – People is more concerned with '*recruiting, conducting individual training, developing and retaining the necessary people with appropriate core skills to meet needs*'. The People component of PMAST is more closely aligned to '*appropriate balance of competencies and correct structure to accomplish its tasks and to ensure appropriate command and control*', which is a function of FIC – Organisation. At the time of writing, this aspect of PMAST has been proposed but not fully implemented [31].

Figure 12 gives the impression of overlap between the tools of the SMSP. For example, in Supplies, there is the RBDDT, PMAST, MAIT and the LAT. However, individual tools form a constituent part of each FIC element, which may then be utilised by other tools contributing to

that FIC element or another FIC element. The combined output from each tool within each FIC ultimately contributes to RAN capability sustainment requirements.

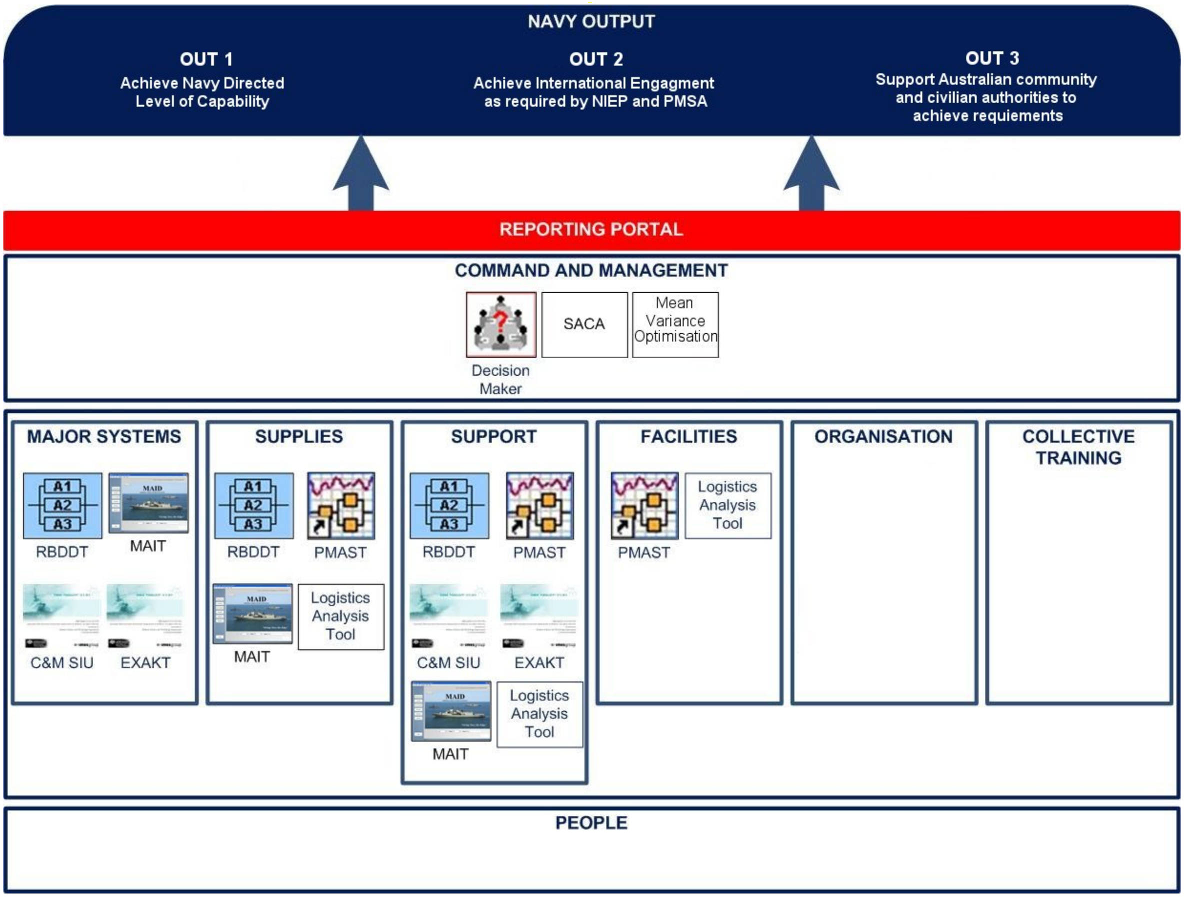

Figure 12: Mapping Sustainment Management Support tools to the FIC and RAN Output

Aside from the tools that contribute directly to the FIC, also included in Figure 12 is the Reporting Portal. While the Reporting Portal does not directly contribute to any FIC, it provides the important functionality of consolidating results and making them easily accessible to all levels of the command and management structure, contributing to:

- balancing current and future capability;
- providing efficient and effective resource use; and
- ensuring clear and comprehensive corporate governance.

As stated, the NSP [4] is one method for supporting the delivery of Navy output and is a short to medium term plan. Even though the SMSP has been mapped against the FIC and has a forward capability planning functionality, it also provides a 'here-and-now' functionality. The tools within the SMSP can also be used to model potential future acquisition sustainment requirements.

When considering the functionality of the SMSP and the themes of the NSP, the SMSP primarily contributes towards the theme of 'Prepare for Operations', with input also

potentially occurring in 'Shape our Future' and 'Leadership'. In particular the SMSP would contribute towards:

- MAJ2: Sustain in-service platforms, equipment and systems;
- SUP1: Ensure ADF logistic systems support Navy activities;
- COM2: Effective and efficient management of resources is embedded in Navy;
- COM7: Successfully introduce new major capability; and
- MAJ1: Acquire new equipment.

All these will ultimately contribute towards the Navy Output:

- OUT1: Achieve Navy Directed Level of Capability.

Also, the NSP identifies risks associated with each theme, referred to as the 'Navy Enterprise Risk Register'. The SMSP would provide input into the management of those risks.

Figure 13 shows the relationship between the SMSP and MSD functions (Policy / Management Advice, Generation and Sustainment) and sub-functions (Configuration Management, Engineering, Inventory Management, Warehousing / Distribution, Repair and Maintenance, Information Management and Governance / Enabling) [32].

Note that some of the functionality within the SMSP map to two or more MSD functional areas. In particular, these are:

- LAT – contributing to Inventory Management and Warehousing / Distribution;
- MAIT – contributing to Repair & Maintenance and Information Management;
- LCOO – contributing to Configuration Management, Engineering, Inventory Management, Warehousing / Distribution, Repair & Maintenance, Information Management and Governance / Enabling; and
- Decision Maker – contributing to Policy / Management Advice, Generation and Sustainment in the areas of Configuration Management, Engineering, Inventory Management, Warehousing / Distribution, Repair & Maintenance, Information Management and Governance / Enabling.

7. Conclusion

The SMSP presents an advanced analysis framework capable of predicting future sustainment requirements. It will assist the SPOs and the RAN to make informed decisions and thereby allocate available resources cost-effectively in relation to platform readiness and sustainability. The outcomes will assist in maximising platform capability and the quantitative analysis of capability management options in relation to maintenance and sparing policies for a range of operational scenarios.

The SMSP provides the means to perform calculations, deductions and predictions, in support of capability management, based on a disparate body of facts, relationships and rules. The SMSP can be aligned with the majority of the FIC:

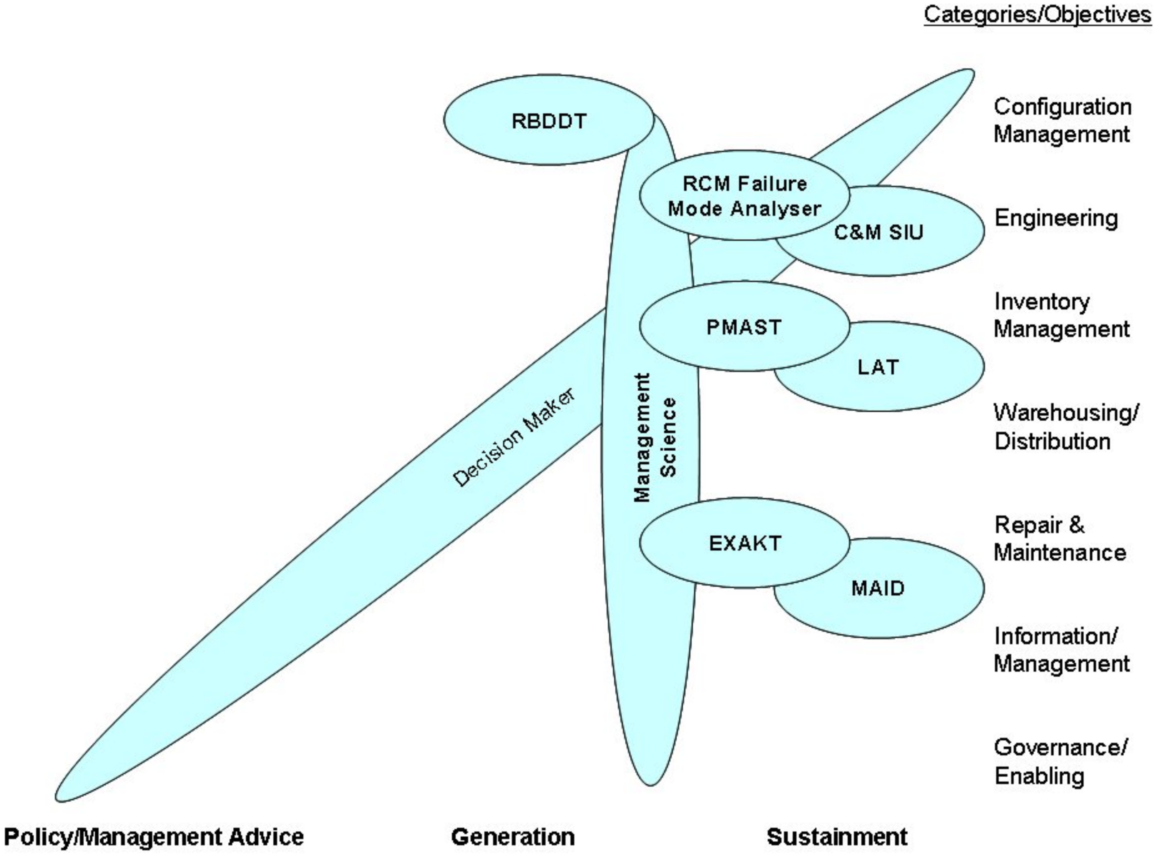

Figure 13: The relationship between the SMSP and MSD functions, which are listed along both axes of the graph [32]

- Command and Management;
- Major Systems;
- Supplies;
- Support; and
- Facilities.

In so doing, the SMSP will encompass much of MSD's activity requirements that contribute to areas of:

- Configuration Management;
- Engineering;
- Repair and Maintenance;
- Inventory Management;
- Warehousing and Distribution;
- Information Management; and
- Governance and Enabling.

The Information Portal will ensure quality data input and the Reporting Portal will provide consistency, timeliness and ease of reporting and will include a reporting functionality that can be customised to the needs of all levels in the chain of command.

It can be seen in Figure 13 that the SMSP contributes to all MSD functional areas and therefore the SMSP contributes towards the DMO purpose and goals. That is, the SMSP will assist MSD reduce LCOO of maritime platforms. To achieve this, the suite of software tools described within the body of this report is required and it is essential that those tools utilise the same data sources and uniformly report their results. The SMSP provides the required common framework.

The potential financial savings that will be realised when the suite of software tools is implemented and operational is difficult to estimate. However, non-financial benefits include: improved governance and accountability; improved capability management, particularly in the reliability, maintenance and support of platforms and systems; and improvements in workforce efficiency.

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19. ABSTRACT The Sustainment Management Support Project (SMSP) will assist Maritime Systems Division (MSD) to reduce its Logistics Cost of Ownership (LCOO) of maritime assets. To achieve this, a suite of software tools is being developed and it is essential that the tools utilise the same data sources and uniformly report their results. The SMSP provides the required common framework for the software tools. The SMSP suite of tools includes data collection and data cleansing; Condition-Based Maintenance (CBM); system reliability and availability analysis; inventory management; prediction of system and Royal Australian Navy (RAN) platform performance and costs for a range of operational profiles; objective decision-making; and identifying potential and actual throughput problems in the MSD business domain.				